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(54) OPTO-ELECTRONIC SCALE-READING APPARATUS.

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Description

Background of the invention

This invention relates to opto-electronic scale-reading apparatus for use in measuring relative displacement of two members. In known such apparatus e.g. British Patent No. 1,504,691 the scale comprises a diffraction grating co-operating with at least one other grating on a read head to produce interference fringes which move relative to the read head during a said displacement of the members, and said measurement is a count of said fringes. It is clear that such a scale has to be of diffraction quality, i.e. the accuracy and reliability of the measurement depends on such parameters as the regularity of the spacing of the scale marks, the sharp definition of the edges of the marks, and the freedom of the scale from scratches and like imperfections. Such a scale can be expensive to produce and protect especially when the scale has to be relatively long.

It is among the objects of this invention to overcome or reduce this difficulty.

It is also known to increase the number of signals obtainable from any two adjacent marks of the scale by phase quadrature interpolation. Known scale-reading apparatus can be subject to phase errors and consequent interpolation errors. It is optionally an object of this invention to overcome or reduce this difficulty.

The scope of the invention is specified in Claim 1 hereto.

It will be seen that in the apparatus according to this invention the diffraction mechanism takes place entirely in the read head. The scale is merely required to provide a pattern of light sources. Thus the scale is not required to be a diffraction grating and the provision of the marks on the scale does not have to be of diffraction quality. The secondary periodicities may be due to the scale having relatively imperfect markings or the markings of the scale may be capable of being produced with greater economy than in known apparatus.

Further, the read head according to this invention is inherently convolutional, i.e. the fringes constitute a convolution of the scale pattern with a substantially sinusoidal pattern. This makes the read head substantially free from phase quadrature errors.

In each of US—A—3,796,498, US—A—4,049,965 and GB—A—2,095,399 there is shown apparatus for measuring displacement between two members wherein use is made of a scale capable of producing diffracted orders. Such a scale must necessarly have marks which have a single periodicity and there is no indication of the presence of secondary periodicities defining departures from a single periodicity or of a spatial filter having a pass band defining a maximum such departure.

Description of preferred embodiments

Embodiments of apparatus according to this invention, will now be described with reference to the accompanying drawings wherein:—

Fig. 1 is a plan view of the apparatus,

Fig. 2 is a perspective view of Fig. 1,

Fig. 3 is an enlarged detail of Fig. 1,

Fig. 4 is a light ray diagram of a first embodiment,

Fig. 5 is a light ray diagram of a second embodiment,

Fig. 6 is a first diagram showing at (a) the response curve of a filter and at (b) a scale periodicity variation,

Fig. 7 is a second diagram showing at (a) the response curve of a filter, at (b) a band of scale periodicities, and at (c) a different position of the latter band,

Fig. 8 is a third diagram showing at (a) the response curve of a filter, at (b) a band of scale periodicities, and at (c) a different position of the latter band,

Fig. 9 shows at (a) an enlarged representation of a scale showing a modulation of the scale marks, and at (b) demonstrating the ramp characteristic of this modulation.

Fig. 10 is a diagram of characteristics of the modulation showing different such characteristics at (a) and (b), and

Fig. 11 is an enlarged representation of a scale showing at (a) amplitude modulation of the scale periodicity and at (b) the binary characteristic of the modulation in this case.

General description of apparatus

Referring to Figs. 1 to 3, there is shown a linear scale 10 secured to a track 11. A read head 12 is secured to a carriage 13 supported on the track 11 for linear movement in a direction X being the direction of the length of the scale. The scale has marks 14 (Figs. 2, 3) defined by lines extending in a direction Y perpendicular to the direction X. The head 12 has an axis 12A extending in a direction Z perpendicular to both the directions X and Y. The head embodies a light source 15 positioned to illuminate the scale over a range 16. The head further comprises, in succession from the scale 10 and along the axis 12A, a first or index grating 17, a second or analyser grating 18, a lens 19, and a sensor assembly 20 preferably comprising sensor sections 21 (Fig. 2) having output signals 22 representing movement of the carriage 13 along the track 11.

The relative position of the scale 10 and the grating 17 is such that the light from the source 15 is reflected at the marks 14 to form a light pattern illuminating the grating 17.

The scale 10 (Fig. 3) comprises a body 10B to which the marks 14 are applied at a given periodicity, i.e. at given periods of pitches. The marks may have a single periodicity indicated by periods P1. Alternatively, the marks may be arranged in accordance with a number of periodicities defining a band, the "scale band", and including said single periodicity as a dominant periodicity among a range of secondary periodicities, all as defined later herein. The scale band may be produced by a random variation in the periods of the markings along the length of the scale.

Said random variations are indicated in Fig. 3, as a surface structure 23 having substantially randomly distributed reflective regions 24 including regions having the period P1. Such a scale profile can be more economical to produce than a scale in which only a single periodicity is present. As will be explained in detail later herein, the apparatus includes a filter F constituted by the grating 17 and by a sampling region 16 spanning a portion of the length of the scale and determining the pass band of the filter F. The dominant periodicity of the light pattern defined by the scale marks 14 lies within the pass band of the filter. The filter responds to the latter light pattern and acts on the sensor 20 to produce the signals 22.

Filter geometry

The regions 24 define notional light sources and the grating 17 is spaced from the scale 10 to be illuminated by said sources and, by diffraction, to produce fringes 30 in a fringe plane 30A located at the side of the grating 17 remote from the scale 10. Referring to Fig. 4, the grating 17 is an amplitude grating, typically a Ronchi grating, and use is made of the diffraction phenomenon known as "self-imaging" of "Fourier imaging" of periodic transmission masks.

This phenomenon requires for this type of grating that the following expressions are satisfied:

$$1/u+1/v=\lambda/(n\times D2^2) \quad (1)$$

$$D2/D3=u/(u+v) \quad (2)$$

$$D2/D1=v/(u+v) \quad (3)$$

wherein:

u=the distance between a generating plane 31A and the grating 17, the plane 31A lying in the XY directions and containing a notional point source 31 being of substantially monochromatic light and giving rise to the fringes 30 which are represented by a square wave, as shown, since these fringes are a self-image of the grating 17;

v=the distance between the gratings, 17, 18;

λ=the wave length of the light;

D1=the pitch of a plurality of said point sources lying in the plane 31A and co-operating to reinforce the fringe pattern;

D2=the pitch of the grating 17;

D3=the pitch of the grating 18;

n=a positive integer.

The head 12 and the scale 10 are matched by making the pitch D1 of the head and the pitch P1 of the scale the same, and the head is so positioned relative to the scale that the plane 31A of the light sources 31 is substantially coincident with the plane, 10A, of the scale. The notional light sources 31 are then actual sources defined by light reflected from surface features of the scale forming the dominant periodicity P1 and associated secondary periodicities.

During relative movement of the head 12 and the scale 10, the resulting movement of the notional light sources 31 in the generating plane 31A in the direction X produces a corresponding movement of the fringes 30, also in the direction X, relative to read head 12. If u and v are equal, the amount of the movement of the fringes 30 relative to the read head 12, is the same as that of said relative movement of the head and the scale. A hypothetical point sensor 21X situated in the plane 30A of the fringes will detect fluctuations in light intensity as the fringes pass across it. The grating 18 has a pitch D3 equal to the fringe pitch D4 and is arranged for its plane 18A to coincide with the plane 30A.

The sensor sections 21 are provided for sensing sub-divisions of the fringe pitch conveniently generated by dividing the grating 18 into sections 18B (Fig. 2) whose grating marks are mutually offset. Four such grating sections 18B, and correspondingly four said sensor sections 21, may be provided to divide the fringe pitch by four. Alternatively, a similar effect is achieved by placing the grating 18 in a tilted position relative to the grating 17 thereby to produce at the plane 30A moire fringes sensed in phase quadrature by the sensor assembly in a manner known per se.

It will be clear that, in this example, the performance of the head 12 is governed by relatively strict adherence to the relationships given by equation (1). Notably, the formation of the fringes is dependent on wave length. Departure from an ideally single wave length causes reduction in contrast of the fringes. This reduction is made worse as the value of n is increased although a high value of n may be desirable for practical reasons e.g. so as not to be restricted to too small a spacing of the head 12 and the scale 10. However, a practical head can be constructed by using values n between 2 and 16, together with a value of 20 μm for D1 and a wave length of 900 nanometers.

Inevitably small variations in the spacing between the head and the scale can produce reading errors. The lens 19 which is introduced to overcome this difficulty is a telecentric device having a front focal plane preferably lying at the scale plane 10A and a rear focal plane lying at the plane, 21A, of the sensor assembly, and the lens 19 allows said variations without necessarily invalidating equation (2) and/or (3).

In the second embodiment (Fig. 5) the parameters of the head 12 are given wholly by:

$$D2/D3=2u/(u+v) \quad (4)$$

$$D2/D1=2v/(u+v) \quad (5)$$

$$1/u+1/v=\lambda/[(n+\tfrac{1}{2})\times D2^2] \quad (6)$$

The restriction of equation (1) does not apply at all in this case. However, equation (6) should be applied when n is low and/or the light is substantially monochromatic. Otherwise, the fringe contrast is substantially independent of wave length and broad-band light, e.g. white light, may be used. Further, in this embodiment, fringes of a

given pitch are formed dependent only on the ratio u/v and not on the absolute values u and v. There is some loss of fringe contrast associated with the formation of fringes in this case, but this is overcome by using a phase grating for the grating 17. Generally, this embodiment would be the preferred embodiment of the invention.

The pitch D1 is also referred to as the "nominal periodicity" of the filter, and the filter may be said to be tuned to read only those marks 14 of the scale 10 which have the nominal periodicity of the filter or as will be explained, which lie within the pass band of the filter.

A housing 12B (Fig. 1) supports the gratings 17, 18 at the spacing v and a support means supports the housing 12B relative to the scale 10 at the distance u between the scale 10 and the grating 17. In the present example said support means is defined by the track 11 and the carriage 13.

Convolution

It can be shown on the basis of Fourier theory, that an optical convolution is performed between the two patterns, being respectively the scale patterns 24 and the fringe patterns 30, due to a single light source 31 illuminating the grating 17 (Figs. 3, 4, 5). Since the fringe pattern is substantially sinusoidal, it can be shown that said convolution represents a spatial filtering of the light distribution of the scale in favour of the spatial periodicity of the fringe pattern produced by said single light source. In other words, the head 12 is a tuned spatial filter. The filtering action is strengthened by a second convolution in this case between the fringe pattern 30 and the grating 18.

The convolutional character of the read head 12 has the advantage that the read head 12 is substantially independent of angular misalignment, particularly about the Z axis, between the read head 12 and the scale 10, thus rendering the read head substantially immune to quadrature phase error due to such misalignment. This is due to the fact that the gratings 17, 18 are fixed one relative to the other and the fringes 30 have a fixed alignment with the lines of the grating 17. Therefore, the head 12 can be set up, relative to the scale, by simple mechanical methods, such as setting gauges and it is not normally necessary, during setting up, to monitor the phase of the signals 22 and make adjustments in the head position to eliminate phase errors as between the respective signals 22.

Relationship of filter and scale

The spatial filter is adapted to pass a band of periodicities constituting the pass band of the filter (or the "filter band") which is the inverse of the length of the illuminated or sampling region 16 (Fig. 1) insofar as that region lies within the optical aperture, 16F, of the grating 17.

The region 16 may be illuminated over a length 16S2 less than a length 16S1 corresponding to the greatest possible aperture 16F of the grating 17 in which case the effective aperture is less than said greatest possible aperture. In any case, the filter band is the inverse of the region 16 i.e. the greater the length of the region 16 the narrower is the filter band and vice versa. In practice, given that the scale has the periodicity P1, the filter F is designed to match the periodicity P1, and the pass band of the filter F is chosen in terms of said region 16. To cope with a given tolerance in the actual periodicity of the scale, i.e. in the spacing of the marks 14, due to manufacturing tolerances, the pass band of the filter is made sufficiently wide to include that tolerance. However, the dominant scale periodicity P1 needs to be detectably present on the scale in the sense of lying within said sampling region 16 and within the pass band of the filter.

Fig. 6 is a diagram showing the relationship between a given pass band FB1 of the filter and the dominant periodicity P1 as the only periodicity of the scale. The curve Fa represents the whole response of the filter F in terms of the contrast FC of the fringes 30 for different scale periodicities SP. A fringe contrast above a line FC1 is sufficient to produce a signal 22 (Fig. 2).

So long as the periodicity P1 lies within the band FB1, the filter F can respond to it and produce a signal 22 of acceptable amplitude. While being uniform within the sampling region, in any one position of the read head along the scale, the periodicity P1 may vary, as between different positions of the sampling region along the scale, over a range P1A and produce a signal 22 so long as the range P1A lies within the filter band FB1. The filter responds in sympathy with any changes in the periodicity within the range P1A.

This is acceptable for a given error tolerance. However, the arrangement has the advantage of relatively good freedom from phase quadrature error. In a typical example, the nominal periodicity is 20 μm and the width of the pass band is 0.1 μm for a sample period 16 of 10 mm. If the range P1A is 0.05 μm, the error tolerance would have to be 0.25%, i.e. 2.5 mm per m. However, this can be compensated for and be reduced, typically, to 20 μm per m.

Fig. 7 shows a band of scale periodicities P1B present within the sampling region 16 and including the dominant periodicity P1 substantially at the centre of the band. If the dominant periodicity coincides with the nominal periodicity of the filter, the filter response is in accordance with the nominal periodicity. However, if, as shown as (c) the position of the scale relative to the pass band of the filter is such that the dominant periodicity lies to one side of the nominal periodicity of the filter, the filter tends to respond to a scale periodicity Px closer to the nominal periodicity of the filter than the dominant periodicity; the dominant periodicity must still lie within the pass band of the filter. A consequence of this arrangement is that the accuracy of the apparatus is higher than in the example of Fig. 6. In other words, the introduction of a band of periodicities about the dominant periodicity,

leads to improved accuracy while still maintaining said relatively good freedom from phase quadrature errors.

Fig. 8 shows a scale band P1C exceeding the filter band FB1. In this case, even though the dominant frequency still remains within the pass band FB1, the filter can see scale periodicities, not only in the pass band, but over the entire range, FB2, of the filter curve Fa. This contributes to building up improved accuracy by virtue of allowing the filter to respond even more closely to its nominal periodicity.

Scale geometry

Fig. 9 represents a part length of the scale 10 showing positions P spaced along the scale at the dominant periodicity defined by the periods P1. A pair of reflective marks 14/1 are provided at two adjacent positions P at regular intervals I along the scale. The intervals I are each an integer multiple of the period P1 and the sampling region 16 substantially extends over a distance equal to one such interval I. In an example, the period P1 is 20 μm, the interval I is 8 mm and the sampling region is 10 mm.

Further reflective marks 14/2 are provided on the scale in positions offset from the positions P by departures or distances D, thus giving rise to secondary periodicities defined by periods P2 which, in this example, vary in accordance with a ramp-shaped characteristic. Alternatively, the characteristic may be sinusoidal (Fig. 10a) within each sampling region with corresponding sinusoidal variation in the secondary periodicities. Alternatively, the distances D may vary so that the characteristic is random (Fig. 10b).

In most cases it is desirable that the maximum departure D from any one position P is less than one half, preferably one quarter, of the period P1 because any greater such departures could result in destructive interference in the filter F such that certain periodicities, including the dominant periodicity, are not detectable. This would lead to a condition that all or some periodicities are no longer detectably present in the apparatus with consequent failure of the reading.

The foregoing departures D may be described as phase or frequency modulation of the scale marks. Amplitude modulation may be provided (Fig. 11) by arranging the marks 14 at selected groups of positions P while leaving the remaining positions P unmarked as shown at PO. The unmarked positions may vary in any appropriate, regular or random pattern.

It would not be appropriate from the modulation point of view if, for example, every second or third position P were unmarked i.e. if the period between any two marks 14 were the same integer multiple of the nominal periodicity D1 of the filter, but this may in fact be done to provide what is in effect a coarse-pitch scale.

Claims

1. Apparatus for measuring displacement between two members, (11, 13); comprising:

a) a scale (10) on one of the members having marks (14; 14/1; 14/2) defined by a light pattern,

b) a read head (12) provided on the other member (13),

c) periodic diffraction means (17) provided in the read head for interacting with said light pattern to produce interference fringes (30) having movement relative to said read head (12) responsive to a said displacement,

d) there being a nominal periodicity (D1, F1) determined by the read head, being the periodicity the scale is required to have to satisfy the optical parameters (D2, u, v) of the read head, and

e) detecting means (18, 20) for detecting said movement, characterised in that

f) the scale marks (14; 14/1; 14/2) have secondary periodicities (24; P1A; P1B; Px; P1C; P2) offset from said nominal periodicity (D1, F1) by departures (D),

g) means (16; 16F; 16S1; 15, 16S2) are provided defining the length of an effective sampling region of the scale (10), only light from said effective sampling region contributing to the production of said interference fringes (30),

h) the diffraction means (17) and said means (16; 16F; 16S1; 15, 16S2) for defining the length of an effective sampling region constitute a spatial filter (F) passing said nominal periodicity (D1, F1), and

i) the filter (F) has a passband (FB1; FB2) determined by the length of said effective sampling region and defining a maximum said departure (D), whereby secondary periodicities below said maximum departure contribute to production of said fringes (30), while secondary periodicities above said maximum departure (D) do not contribute to production of said fringes (30).

2. Apparatus according to Claim 1, wherein said diffraction means (17) comprises a diffraction grating (17) spaced from the scale (10) to be illuminated by said light pattern (14, 31) and to produce said diffraction fringes (30) at a plane (30A) spaced from said grating (17) to the side thereof remote from the scale (10).

3. Apparatus according to Claim 1 wherein said spatial filter (F) comprises a first diffraction grating (17) spaced from the scale (10) to be illuminated by said light pattern (14, 31) and to produce said fringes (30) at a fringe plane (30A) to the side of the first grating (17) remote from the scale (10), and wherein the detecting means comprise a second grating (18) situated at said plane (30A) to reveal a light modulation due to said movement of the fringes (30), the light from said light pattern (14, 31) passing in succession through the first and second gratings (17, 18) to the side of the second grating (18) remote from the first grating (17), and a sensor assembly (20) provided at said remote side of the second grating (18) for sensing said modulation.

4. Apparatus according to Claim 3 wherein the parameters (D2, u, v) of said read head (12) are given by expressions:

$$1/u+1/v=\lambda/(n\times D2^2) \quad (1)$$

$$D2/D3=u/(u+v) \quad (2)$$

$$D2/D1=v/(u+v) \quad (3)$$

wherein:
u=the distance between a plane (31A) containing said light pattern (31); and said first grating (17);
v=the distance between said gratings, (17, 18);
λ=the wave length of the light;
D1=the pitch of said nominal periodicity
D2=the pitch of said first grating (17);
D3=the pitch of said second grating (18);
n=a positive integer.

5. Apparatus according to Claim 3 wherein the parameters (D2, u, v) of said read head 12 are given by the expressions:

$$D2/D3=2u/(u+v) \quad (4)$$

$$D2/D1=2v/(u+v) \quad (5)$$

wherein:
u=the distance between a plane containing said light pattern and said first grating (17)
v=the distance between said gratings (17, 18)
D1=the pitch of said nominal periodicity
D2=the pitch of the first grating (17);
D3=the pitch of said second grating (18).

6. Apparatus according to Claim 1 wherein said spatial filter (F) has an optical aperture (16F) dimensioned to read a corresponding sampling region (16) of the scale and said filter band (FB) is inversely proportional to said sampling region.

7. Apparatus according to Claim 1 wherein said spatial filter (F) has an optical aperture (16F) dimensioned to read a corresponding first reading range (16S1) of said scale (10) and limiting means (15) for limiting the scale (10) to a second reading range (16S2) less than a said first reading range (16S1) whereby a sampling region (16) of the scale is defined by said second reading range (16S2) and said filter band (FB) is inversely proportional to said second reading range (16S2).

8. Apparatus according to Claim 6 or Claim 7 wherein a dominant periodicity (P1) of said scale (10) is defined by positions (P) spaced along the scale, said dominant periodicity being equal to the nominal periodicity of the spatial filter (F), a said scale mark (14) is provided substantially at each said position (P), such that the spacing of the marks (14) is uniform at least within said sampling region (16), and any non-uniformities in said spacing of the marks lie within said pass band (FB1) of the filter (F).

9. Apparatus according to Claim 6 or Claim 7 wherein a dominant periodicity (P1) of said scale (10) is defined by dominant positions (P) equally spaced along the scale (10), said dominant periodicity (P1) is equal to the nominal periodicity (D1, F1) of the spatial filter (F), at least two scale marks (14/1) are present at respective said positions P within said sampling region (16), secondary said marks (14/2) are provided on the scale (10) in positions offset from said dominant positions (P) thereby to provide secondary periodicities (P2) combining to define a scale band (SB1), and said scale band (SB1) lies within said pass band (FB1) of the filter (F).

10. Apparatus according to Claim 9 wherein said spatial filter (F) defines a response curve (Fa) covering a range of periodicities (FB2) greater than said pass band (FB1) of the filter (F), said secondary periodicities (P2) extend at least over said greater range (FB2).

11. Apparatus according to Claim 1 wherein a dominant periodicity (P1) of said scale is defined by positions (P) equally spaced along the scale, said dominant periodicity (P1) being equal to said nominal periodicity (D1, F1) of the spatial filter (F), and said scale marks (14) are provided at selected said dominant positions (F3) only.

12. Apparatus according to Claim 6 or Claim 7 wherein said read head (12) includes a light source (15) positioned to illuminate said scale (10) at said sampling region (16), and by reflection at said marks (14) produce the light pattern (14, 31) illuminating said diffraction means (17).

13. Apparatus according to Claim 12 as dependent on Claim 7 wherein said light source (15) is adapted to illuminate said second reading range (16S2) only thereby to limit said sampling region (16).

14. Apparatus according to Claim 1 wherein the secondary periodicities arise by virtue of a random variation in the period of the marks along the scale.

15. Apparatus according to Claim 1 wherein the secondary periodicities arise by virtue of a ramp-shaped variation in the period of the marks.

16. Apparatus according to Claim 1 wherein the secondary periodicities arise by of virtue of a sinusoidal variation in the period of the marks.

17. Apparatus according to Claim 1 wherein the secondary periodicities arise by virtue of scratches or like imperfections of the scale.

18. Apparatus according to Claim 1 wherein said spatial filter (F) has an optical aperture (16; 16F; 16S1; 16S2), and said pass band (FB1; FB2) is defined by the extent of said aperture.

19. Apparatus according to Claim 5 wherein the parameters of said read head (12) are additionally given by the expression

$$1/u+1/v=\lambda/[(n+\tfrac{1}{2})\times D2^2] \quad (6)$$

wherein λ is the wave length of the light employed.

20. Apparatus according to Claim 5 or Claim 19 wherein said periodic diffraction means (17) is a phase grating.

Patentansprüche

1. Vorrichtung zum Messen des Versatzes zwischen zwei Elementen (11, 13), mit:

a) einer Skala (10) an einem der Elemente mit durch ein Lichtverteilungsmuster bestimmten Markierungen (14; 14/1; 14/2),

b) einem an dem anderen Element (13) vorgesehenen Lesekopf (12),

c) in dem Lesekopf zur Wechselwirkung mit dem Lichtverteilungsmuster vorgesehenem periodischen Brechungsmittel (17), um Interferenzstreifen (30) zu erzeugen mit einer von einem besagten Versatz abhängigen Bewegung relativ zum Lesekopf (12);

d) wobei eine Nenn-Periodizität (D1, F1) durch den Lesekopf bestimmt ist, welche die Periodizität ist, die die Skala besitzen sollte, um den optischen Parametern (D2, u, v) des Lesekopfes zu genügen, und

e) Erfassungsmitteln (18, 20) zum Erfassen der Bewegung, dadurch gekennzeichnet, daß

f) die Skalenmarkierungen (14; 14/1; 14/2) gegenüber der Nenn-Periodizität (D1, F1) um Abweichungen (D) versetzte Sekundär-Periodizitäten (24; P1A; P1B; Px; P1C; P2) besitzen,

g) Mittel (16, 16F; 16S1; 15, 16S2) vorgesehen ist, welches die Länge eines effektiven Abtastbereiches der Skala (10) definiert, wobei nur Licht aus dem effektiven Abtastbereich zu der Erzeugung der Interferenzstreifen (30) beiträgt,

h) das Brechungsmittel (17) und die Mittel (16; 16F; 16S1; 15, 16S2) zum Definieren der Länge eines effektiven Abtastbereiches ein die Nenn-Periodizität (D1, F1) durchlassendes Raumfilter (F) bilden, und

i) das Filter (F) ein durch die Länge des effektiven Abtastbereiches bestimmtes Durchlaßband (FB1; FB2) besitzt, welches eine maximale Abweigung (D) bestimmt, wodurch Sekundär-Periodizitäten unter der maximalen Abweichung zur Erzeugung der Streifen (30) beitragen, während Sekundär-Periodizitäten über der maximalen Abweichung (D) nicht zur Erzeugung der Streifen (30) beitragen.

2. Vorrichtung nach Anspruch 1, bei der das Brechungsmittel (17) ein Brechungsgitter (17) mit Abstand von der Skala (10) umfaßt, zur Beleuchtung durch das Lichtverteilungsmuster (14, 31) und zur Erzeugung der Brechungsstreifen (30) an einer Ebene (30A) mit Abstand von dem Gitter (17) and dessen von der Skala (10) abgelegenen Seite.

3. Vorrichtung nach Anspruch 1, bei der das Raumfilter (F) ein erstes Brechungsgitter (17) mit Abstand von der Skala (10) zur Beleuchtung durch das Lichtverteilungsmuster (14, 31) und zur Erzeugung der Streifen (30) in einer Streifenebene (30A) zu der von der Skala (10) abgelegenen Seite des ersten Gitters (17) umfaßt, und bei der die Erfassungsmittel umfassen ein in der Ebene (30A) gelegenes zweites Gitter (18), um eine Lichtmodulation infolge der Bewegung der Streifen (30) zu zeigen; wobei das Licht von dem Lichtverteilungsmuster (14, 31) aufeinanderfolgend durch das erste und das zweite Gitter (17, 18) zu der von dem ersten Gitter (17) abgelegenen Seite des zweiten Gitters (18) hindurchtritt und eine an der abgelegenen Seite des zweiten Gitters (18) vorgesehen Fühleranordnung (20) zum Erfassen der Modulation.

4. Vorrichtung nach Anspruch 3, bei der die Parameter (D2, u, v) des Lesekopfes (12) gegeben sind durch Ausdrücke:

$$1/u+1/v=\lambda/(n\times D2^2) \qquad (1)$$

$$D2/D3=u/(u+v) \qquad (2)$$

$$D2/D1=v/(u+v) \qquad (3)$$

wobei:

u=der Abstand zwischen einer das Lichtverteilungsmuster (31) enthaltenden Ebene (31A) und dem ersten Gitter (17);
v=der Abstand zwischen den Gittern (17, 18);
λ=die Lichtwellenlänge;
D1=die Schrittweite der Nenn-Periodizität;
D2=die Schrittweite des ersten Gitters (17);
D3=die Schrittweite des zweiten Gitters (18); und
n=eine positive ganze Zahl.

5. Vorrichtung nach Anspruch 3, bei der die Parameter (D2, u, v) des Lesekopfes (12) gegeben sind durch die Ausdrücke:

$$D2/D3=2u/(u+v) \qquad (4)$$

$$D2/D1=2v/(u+v) \qquad (5)$$

wobei:

u=der Abstand zwischen einer das Lichtverteilungsmuster enthaltenden Ebene und dem ersten Gitter (17);
v=der Abstand zwischen den Gittern (17, 18);
D1=die Schrittweite der Nenn-Periodizität;
D2=die Schrittweite des ersten Gitters (17); und
D3=die Schrittweite des zweiten Gitters (18).

6. Vorrichtung nach Anspruch 1, bei der das Raumfilter (F) eine optische Apertur (16F) besitzt, die bemessen ist zum Lesen eines entsprechenden Abtastbereiches (16) der Skala und das Filterband (FB) umgekehrt proportional zu dem Abtastbereich ist.

7. Vorrichtung nach Anspruch 1, bei der das Raumfilter (F) eine optische Apertur (16F) besitzt, die bemessen ist zum Lesen eines entsprechenden ersten Lesebereichs (16S1) der Skala (10), und Begrenzungsmittel (15) zum Begrenzen der Skala (10) auf einen zweiten Lesebereich (16S2) kleiner als ein besagter erster Lesebereich (16S1), wodurch ein Abtastbereich (16) der Skala definiert ist durch den zweiten Lesebereich (16S2), und das Filterband (FB) zu dem zweiten Lesebereich (16S2) umgekehrt proportional ist.

8. Vorrichtung nach Anspruch 6 oder Anspruch 7, bei der eine dominante Periodizität (P1) der Skala (10) definiert ist durch mit Abstand längs der Skala vorhandene Positionen (P), wobei die dominante Periodizität gleich der Nenn-Periodizi-

des Raumfilters (F) ist, eine besagte Skalenmarrung (14) im wesentlichen an jeder besagten sition (P) vorgesehen ist, so daß die Abstandhalıg der Markierungen (14) zumindest innerhalb s Abtastbereiches (16) gleichmäßig ist und endwelche Ungleichmäßigkeiten in der ıstandhaltung der Markierungen innerhalb des ırchlaßbandes (FB1) des Filters (F) liegen.

9. Vorrichtung nach Anspruch 6 oder 7, bei der ıe dominante Periodizität (P1) der Skala (10) ırch gleichmäßig längs der Skala (10) mit ɔständen versehene dominante Positionen (P) finiert ist, wobei die dominante Periodizität (P1) eich der Nenn-Periodizität (D1, F1) des Raumfilrs (F) ist, mindestens zwei Skalenmarkierungen 4/1) an jeweiligen besagten Positionen (P) innerılb des Abtastbereiches (16) vorhanden sind, kundäre besagte Markierungen (14/2) an der kala (10) an gegen die dominanten Positionen (P) ersetzten Stellen vorgesehen sind, um dadurch ekundär-Periodizitäten (P2) zu schaffen, die sich um Bestimmen eines Skalenbandes (SB1) kombiieren, und das Skalenband (SB1) innerhalb des Durchlaßbandes (FB1) des Filters (F) liegt.

10. Vorrichtung nach Anspruch 9, bei der das laumfilter (F) eine Ansprechkurve (Fa) bestimmt, welche einen Bereich von Periodizitäten (FB2) größer als das Durchlaßband (FB1) des Filters (F) überdeckt, wobei die Sekundär-Periodizitäten (P2) sich mindestens über den größeren Bereich (FB2) erstrecken.

11. Vorrichtung nach Anspruch 1, bei der eine dominante Periodizität (P1) der Skala durch mit gleichem Abstand längs der Skala angeordnete Positionen (P) bestimmt ist, die dominante Periodizität (P1) gleich der Nenn-Periodizität (D1, F1) des Raumfilters (F) ist und die Skalenmarkierungen (14) nur an ausgewählten der besagten dominanten Positionen (F3) vorgesehen sind.

12. Vorrichtung nach Anspruch 6 oder 7, bei der der Lesekopf (12) eine Lichtquelle (15) enthält, die zur Beleuchtung der Skala (10) an dem Abtastbereich (16) positioniert ist und durch Reflexion an den Markierungen (14) das das Brechungsmittel (17) beleuchtende Lichtverteilungsmuster (14, 31) erzeugt.

13. Vorrichtung nach Anspruch 12 in Abhängigkeit von Anspruch 7, bei der die Lichtquelle (15) zum Beleuchten nur des zweiten Ablesebereichs (16S2) ausgelegt ist, um dadurch den Abtastbereich (16) zu begrenzen.

14. Vorrichtung nach Anspruch 1, bei der die Sekundär-Periodizitäten infolge einer Zufallsvariation des Wiederholabstandes der Markierungen längs der Skala entstehen.

15. Vorrichtung nach Anspruch 1, bei der die Sekundär-Periodizitäten infolge einer rampenförmigen Veränderung des Wiederholabstandes der Markierungen entstehen.

16. Vorrichtung nach Anspruch 1, bei der die Sekundär-Periodizitäten infolge einer sinusförmigen Veränderung des Wiederholabstandes der Markierungen entstehen.

17. Vorrichtung nach Anspruch 1, bei der die Sekundär-Periodizitäten infolge von Kratzern oder ähnlichen Unvollkommenheiten der Skala entstehen.

18. Vorrichtung nach Anspruch 1, bei der das Raumfilter (F) eine optische Apertur (16; 16F; 16S1; 16S2) besitzt und das Durchlaßband (FB1; FB2) durch das Ausmaß der Apertur bestimmt ist.

19. Vorrichtung nach Anspruch 5, bei der Parameter des Lesekopfes (12) zusätzlich gegeben sind durch den Ausdruck

$$1/u+1/v=\lambda/[(n+\tfrac{1}{2})\times D2^2] \qquad (6)$$

wobei λ die Wellenlänge des benutzten Lichtes ist.

20. Vorrichtung nach Anspruch 5 oder 19, bei der das periodische Brechungsmittel (17) ein Phasengitter ist.

Revendications

1. Appareil pour mesurer le déplacement entre deux éléments (11, 13), comprenant:

a) une graduation (10) sur un des éléments, possédant des repères (14; 14/1; 14/2) définies par un modèle lumineux,

b) une tête de lecture (12) prévue sur l'autre élément (13),

c) des moyens de diffraction périodique (17) prévus dans la tête de lecture pour une interaction avec le modèle lumineux afin de produire des franges d'interférence (30) possédant un mouvement par rapport à la tête de lecture (12) en réponse à un déplacement entre les deux éléments (11, 13),

d) une périodicité nominale (D1, F1) étant déterminée par la tête de lecture, qui est la périodicité que doit posséder la graduation afin de satisfaire aux paramètres optiques (D2, u, v) de la tête de lecture, et

e) des moyens de détection (18, 20) pour détecter le mouvement précité, caractérisé en ce que

f) les repères de graduation (14; 14/1; 14/2) possèdent des périodicités secondaires (24; P1A; P1B; Px; P1C; P2) décalées de déviations (D) par rapport à la périodicité nominale (D1, F1),

g) des moyens (16; 16F; 16S1; 15, 16S2) sont prévus pour définir la longueur d'une région d'échantillonnage effectif de la graduation (10), seule la lumière provenant de cette région d'échantillonnage effectif contribuant à la production des franges d'interférence (30),

h) les moyens de diffraction (17) et les moyens précités (16; 16F; 16S1; 15, 16S2) pour définir la longueur d'une région d'échantillonnage effectif, constituent un filtre spatial (F) passant la périodicité nominale (D1, F1), et

i) le filtre (F) possède une bande passante (FB1; FB2) déterminée par la longueur de la région d'échantillonnage effectif et définissant une déviation (D) maximale, de sorte que les périodicités secondaires en dessous de cette déviation maximale contribuent à la production des franges (30), tandis que les périodicités secondaires au-dessus de cette déviation maximale (D) ne contribuent pas à la production des franges (30).

2. Appareil selon la revendication 1, dans lequel

les moyens de diffraction (17) comprennent un réseau de diffraction (17) distant de la graduation (10) afin d'être éclairé par le modèle lumineux (14, 31) et de produire les franges de diffraction (30) sur un plan (30A) distant du réseau (17) du côté de ce dernier qui est opposé à la graduation (10).

3. Appareil selon la revendication 1, dans lequel le filtre spatial (F) comprend un premier réseau de diffraction (17) distant de la graduation (10) afin d'être éclairé par le modèle lumineux (14, 31) et de produire les franges (30) sur un plan de franges (30A) du côté du premier réseau (17) qui est opposé à la graduation (10), et dans lequel les moyens de détection comprennent un deuxième réseau (18) situé sur le plan (30A) pour révéler une modulation lumineuse par suite du mouvement des franges (30), la lumière provenant du modèle lumineux (14, 31) passant successivement par les premier et deuxième réseaux (17, 18) du côté du deuxième réseau (18) qui est opposé au premier réseau (17), et un ensemble détecteur (20) est prévu sur ce côté opposé du deuxième réseau (18) pour détecter la modulation précitée.

4. Appareil selon la revendication 3, dans lequel les paramètres (D2, u, v) de la tête de lecture (12) sont fournis par les expressions suivantes:

$$1/u+1/v=\lambda/(n\times D2^2) \qquad (1)$$

$$D2/D3=u/(u+v) \qquad (2)$$

$$D2/D1=v/(u+v) \qquad (3)$$

où:

u=distance entre un plan (31a) contenant le modèle lumineux (31), et le premier réseau (17);

v=distance entre les réseaux (17, 18);

λ=longueur d'onde de la lumière;

D1=pas de la périodicité nominale;

D2=pas du premier réseau (17);

D3=pas du deuxième réseau (18);

n=intégrateur positif.

5. Appareil selon la revendication 3, dans lequel les paramètres (D2, u, v) de la tête de lecture (12) sont fournis par les expressions suivantes:

$$D2/D3=2u(u+v) \qquad (4)$$

$$D2/D1=2v/(u+v) \qquad (5)$$

où:

u=distance entre un plan (31a) contenant le modèle lumineux, et le premier réseau (17);

v=distance entre les réseaux (17, 18);

D1=pas de la périodicité nominale;

D2=pas du premier réseau (17);

D3=pas du deuxième réseau (18).

6. Appareil selon la revendication 1, dans lequel le filtre spatial (F) possède une ouverture optique (16F) dimensionnée pour lire une région d'échantillonage correspondante (16) de la graduation, et la bande filtrante (FB) est inversement proportionnelle à cette région d'échantillonnage.

7. Appareil selon la revendication 1, dans lequel le filtre spatial (F) possède une ouverture optique (16F) dimensionnée pour lire une première plage de lecture correspondante (16S1) de la graduation (10), et des moyens limiteurs (15) pour limiter la graduation (10) à une deuxième plage de lecture (16S2) au-dessus de la première plage de lecture (16S1), de sorte qu'une région d'échantillonnage (16) de la graduation est définie par la deuxième plage de lecture (16S2), et la bande filtrante (FB) est inversement proportionnelle à cette deuxième plage de lecture (16S2).

8. Appareil selon la revendication 6 ou 7, dans lequel une périodicité dominante (P1) de la graduation (10) est définie par des positions (P) espacées le long de la graduation, cette périodicité dominante étant égale à la périodicité nominale du filtre spatial (F), un repère de graduation (14) est prévu sensiblement à chaque position (P), de sorte que l'espacement des repères (14) est uniforme au moins à l'intérieur de la région d'échantillonnage (16), et tous les éventuels défauts d'uniformité de l'espacement des repères se situent dans la bande passante (FB1) du filtre (F).

9. Appareil selon la revendication 6 ou 7, dans lequel une périodicité dominante (P1) de la graduation (10) est définie par des positions dominantes (P) régulièrement espacées le long de la graduation (10), cette périodicité dominante (P1) est égale à la périodicité nominale (D1, F1) du filtre spatial (F), au moins deux repères de graduation (14/1) sont présents à des positions (P) respectives à l'intérieur de la région d'échantillonnage (16), des repères secondaires (14/2) sont prévus sur la graduation (10) à des positions décalées par rapport aux position dominantes (P), de manière à fournir des périodicités secondaires (P2) qui se combinent pour définir une bande de graduation (SB1), et la bande de graduation se situe dans la bande passante (FB1) du filtre (F).

10. Appareil selon la revendication 9, dans lequel le filtre spatial (F) définit une courbe de réponse (Fa) couvrant une plage de périodicités (FB2) plus grande que la bande passante (FB1) du filtre (F), et les périodicités secondaires (P2) s'étendent au moins sur cette plage plus grande (FB2).

11. Appareil selon la revendication 1, dans lequel une périodicité dominante (P1) de la graduation est définie par des positions (P) régulièrement espacées le long de la graduation cette périodicité dominante (P1) étant égale à la périodicité nominale (D1, F1) du filtre spatial (F), et les repères de graduation (14) sont prévus uniquement à des positions dominantes sélectionnées (F3).

12. Appareil selon la revendication 6 ou 7, dans lequel la tête de lecture (12) comprend une source lumineuse (15) positionnée pour éclairer la graduation (10) sur la région d'échantillonnage (16) et, par réflexion sur les repères (14), pour produire le modèle lumineux (14, 31) éclairant les moyens de diffraction (17).

13. Appareil selon la revendication 12, dans lequel la source lumineuse (15) est conçue pour éclairer uniquement la deuxième plage de lecture

(16S2), délimitant ainsi la région d'échantillonnage (16).

14. Appareil selon la revendication 1, dans lequel les périodicités secondaires surviennent sous l'effet d'une variation aléatoire de la période des repères le long de la graduation.

15. Appareil selon la revendication 1, dans lequel les périodicités secondaires surviennent sous l'effet d'une variation en forme de rampe de la période des repères.

16. Appareil selon la revendication 1, dans lequel les périodicités secondaires surviennent sous l'effet d'une variation sinusoïdale de la période des repères.

17. Appareil selon la revendication 1, dans lequel les périodicités secondaires surviennent sous l'effet de rayures ou imperfections similaires de la graduation.

18. Appareil selon la revendication 1, dans lequel le filtre spatial (F) possède une ouverture optique (16; 16F; 16S1; 16S2), le la bande passante (FB1; FB2) est définie par l'étendue de cette ouverture.

19. Appareil selon la revendication 5, dans lequel les paramètres de la tête de lecture (12) sont en outre fournis par l'expression suivante:

$$1/u+1/v=\lambda/[(n+1/2)\times D2^2] \qquad (6)$$

où λ est la longueur d'onde de la lumière employée.

20. Appareil selon la revendication 5 ou 19, dans lequel les moyens de diffraction périodiques (17) consistent en un réseau de phase.

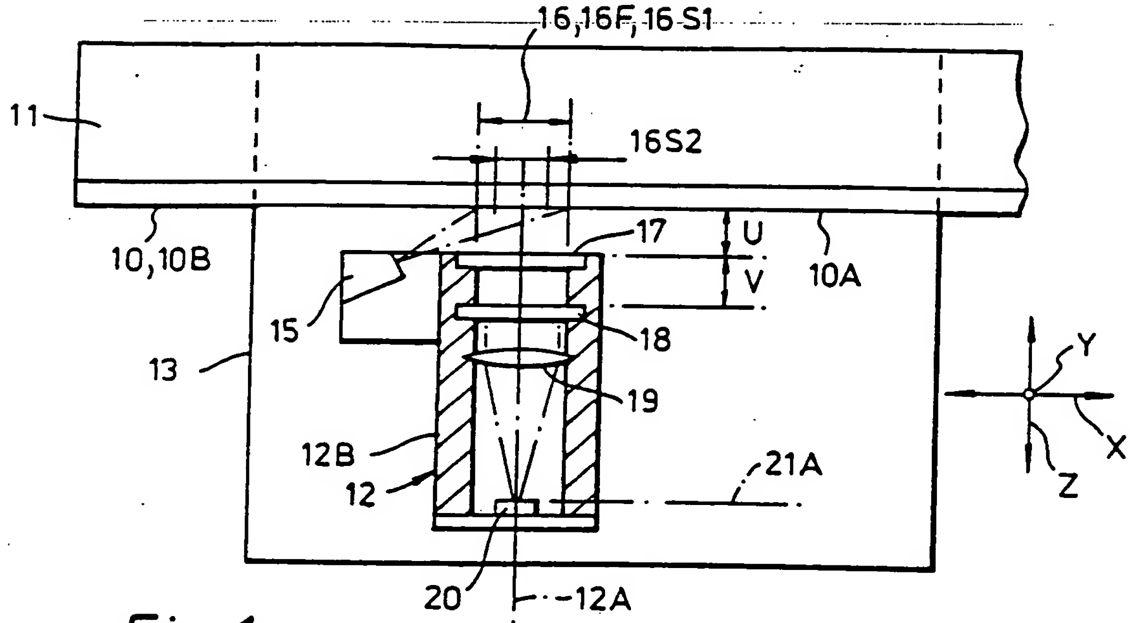

16,16F,16-S1
11
16S2
17
U
V
10,10B
10A
15
18
13
19
12B
21A
12
20
12A
Y
X
Z

Fig.1.

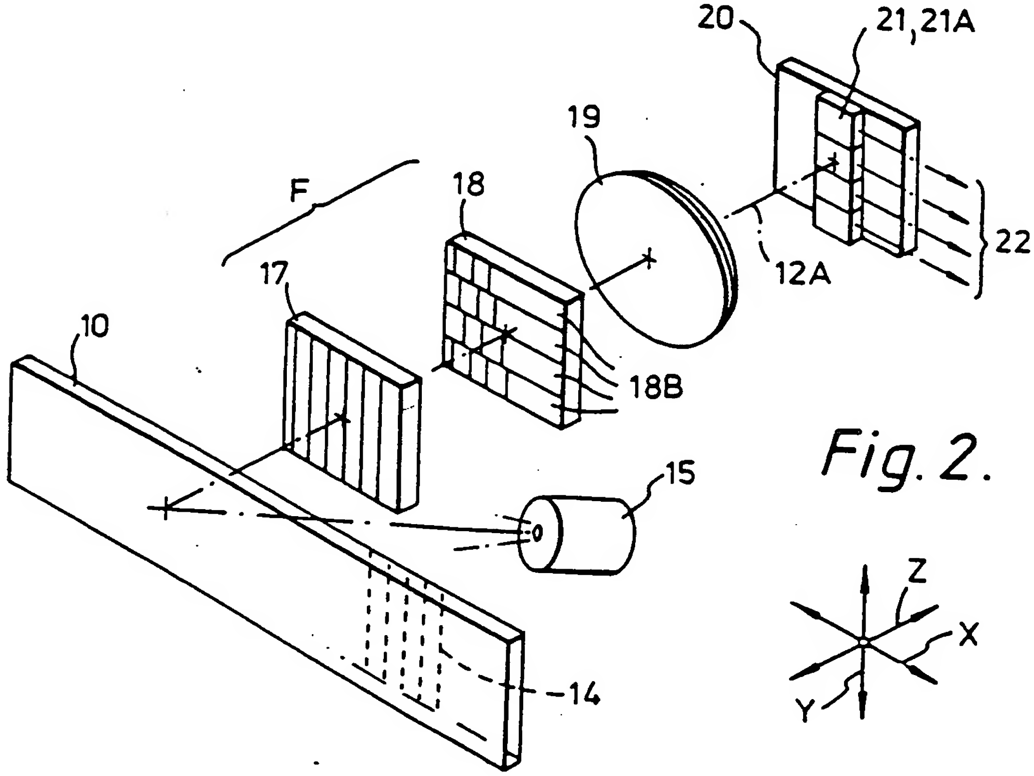

20
21,21A
19
F
18
22
12A
17
10
18B
15
Z
X
Y
14

Fig. 2.

Fig.3.

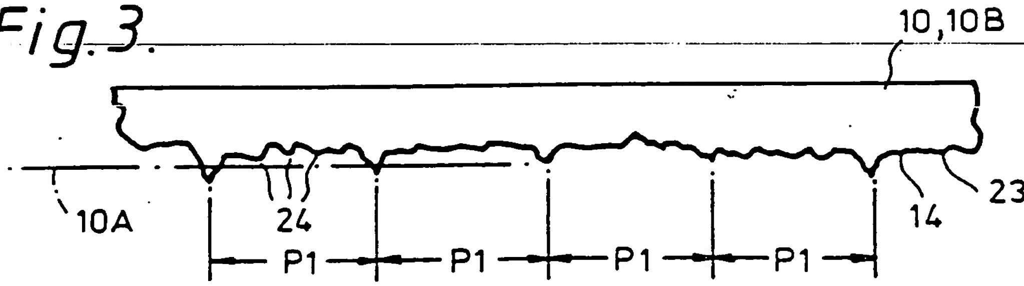


Fig.4.

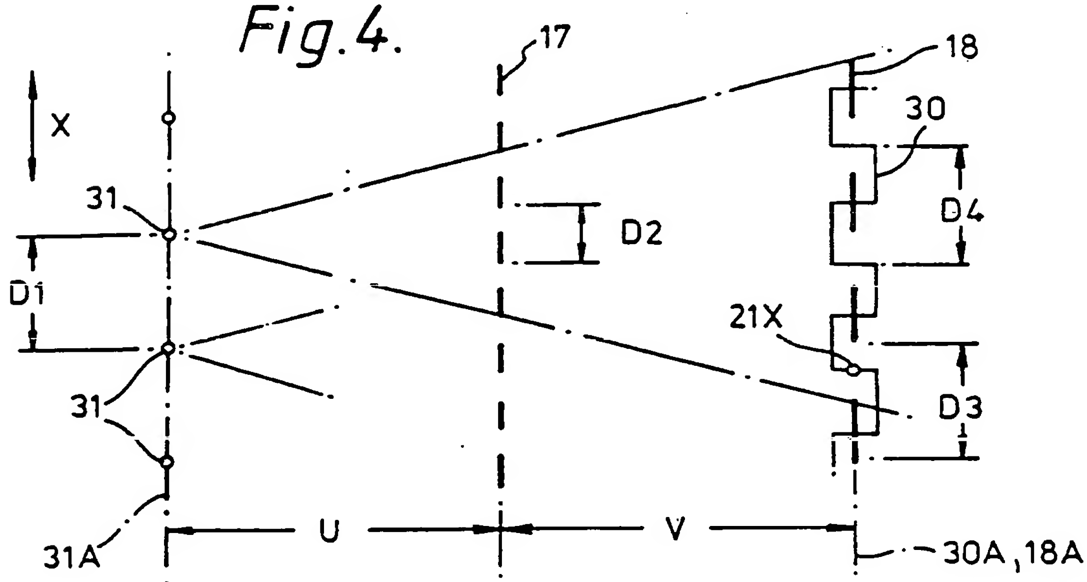
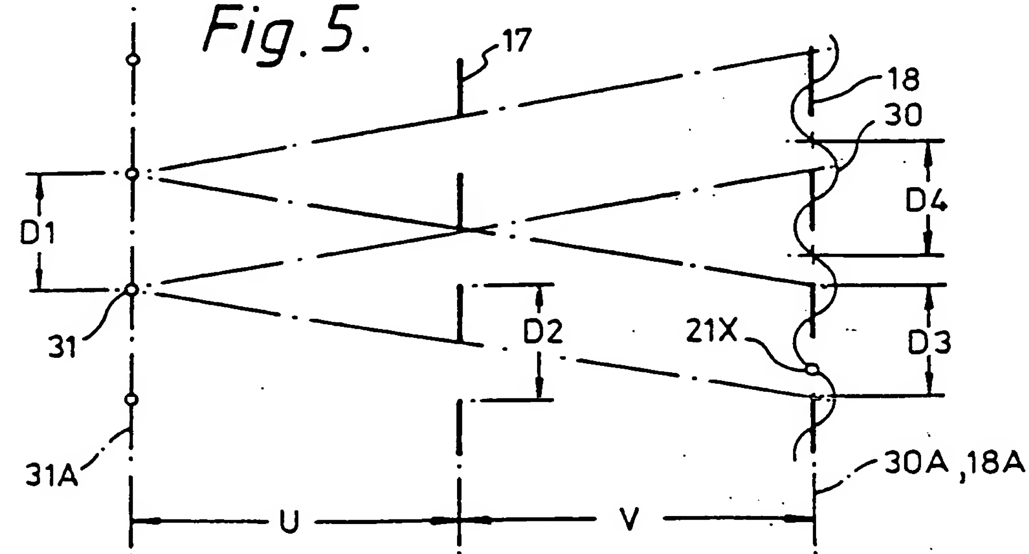


Fig.5.



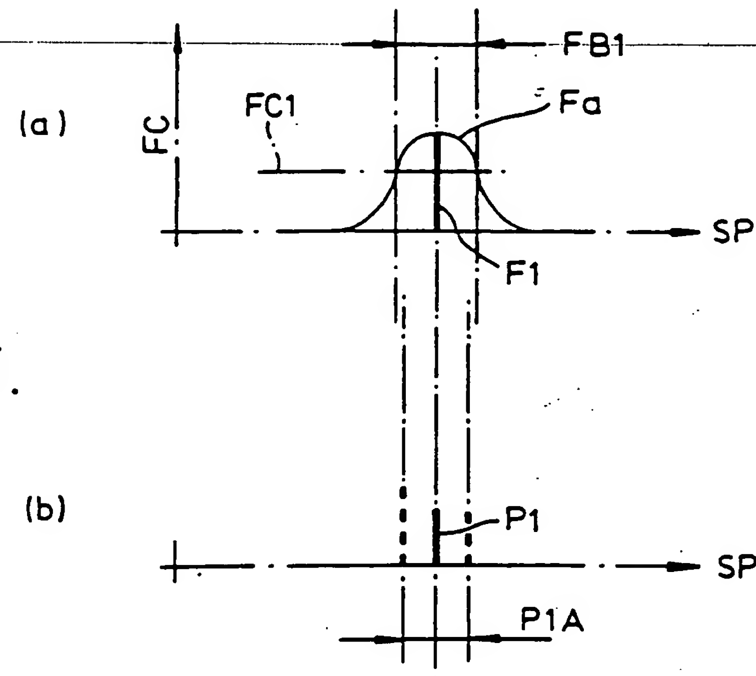

(a)
FC
FC1
FB1
Fa
F1
SP
(b)
P1
SP
P1A

Fig. 6.

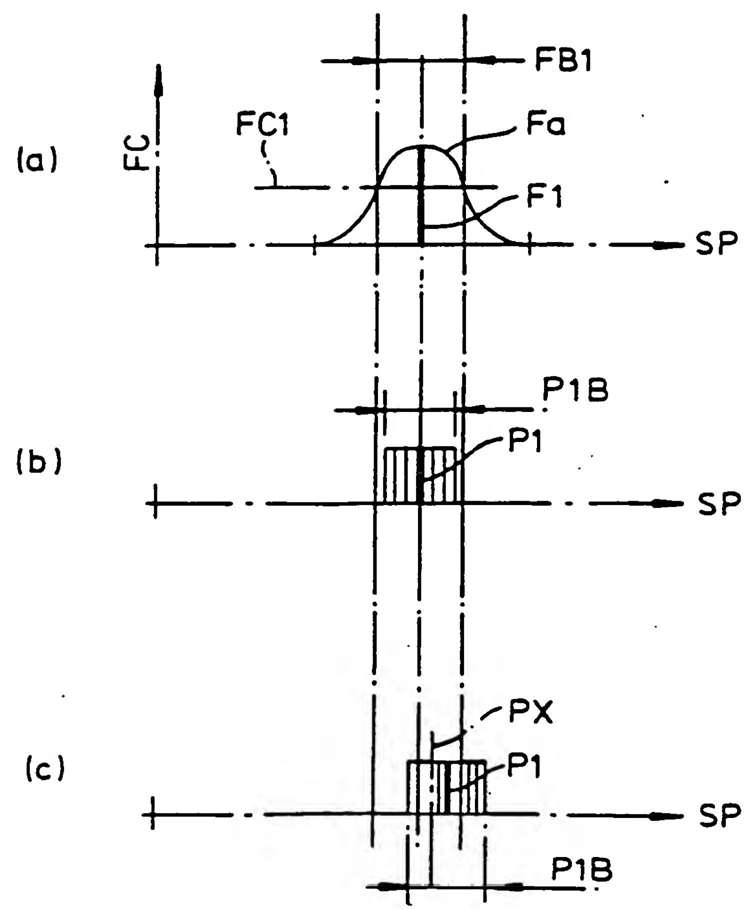

(a)
FC
FC1
FB1
Fa
F1
SP
(b)
P1B
P1
SP
(c)
PX
P1
SP
P1B

Fig.7.

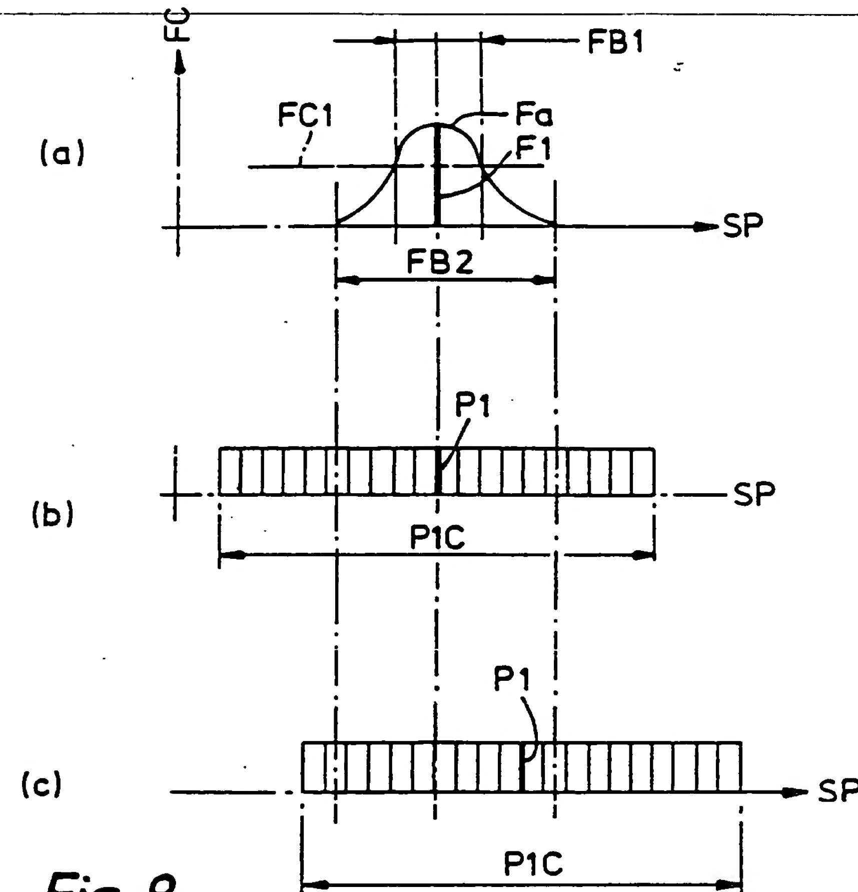
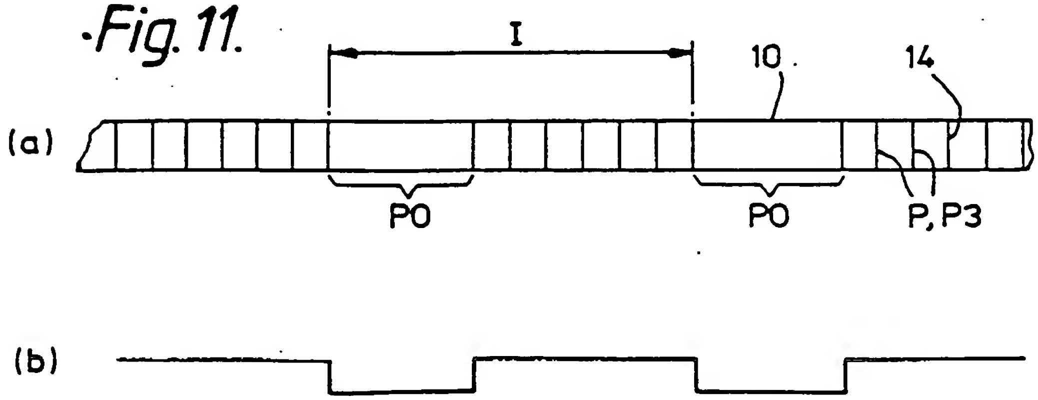


Fig. 8.

Fig. 11.



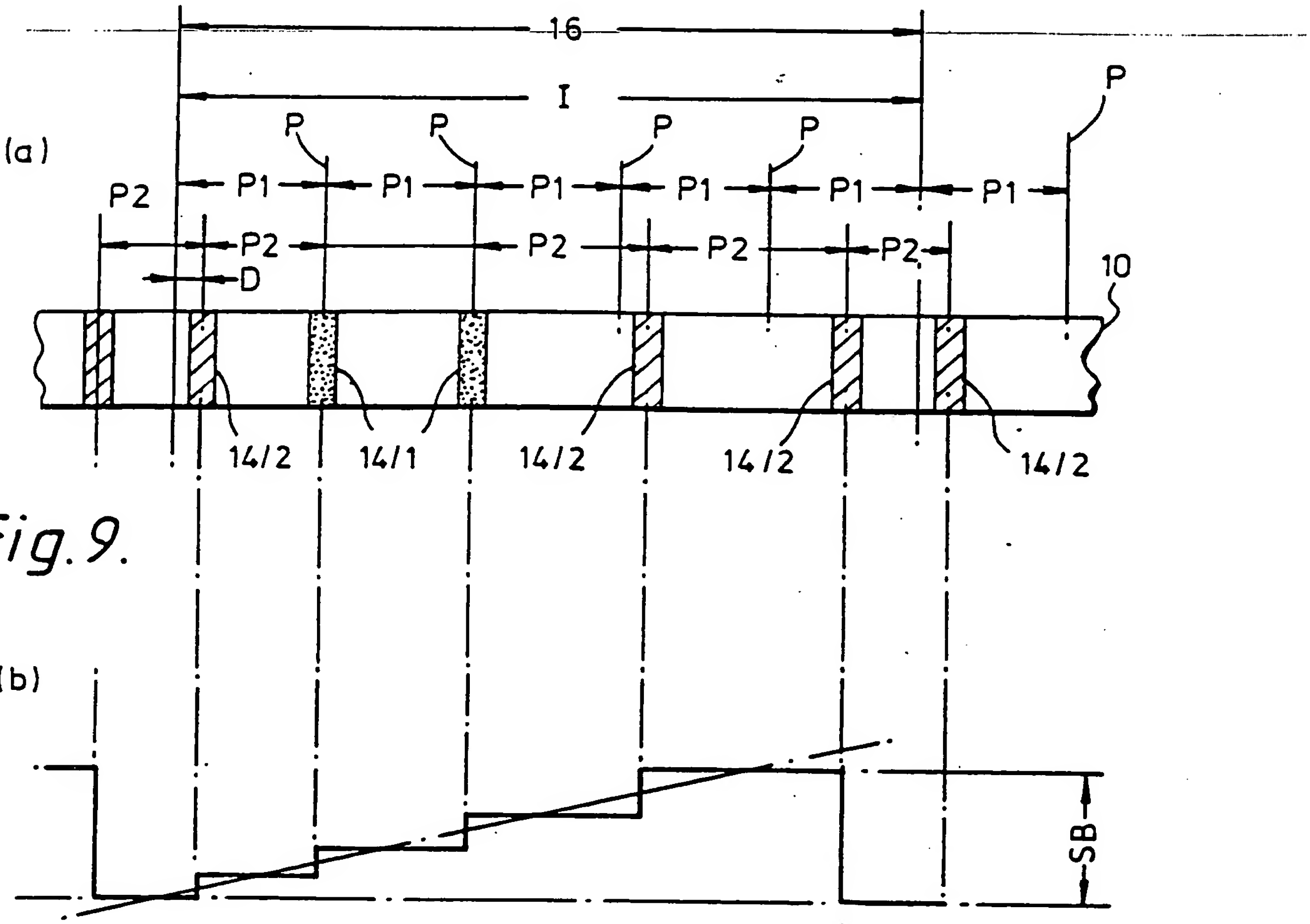

16
I
(a)
P
P
P
P
P
P2
P1
P1
P1
P1
P1
P1
P2
P2
P2
P2
D
10
14/2
14/1
14/2
14/2
14/2
(b)
SB

Fig.9.

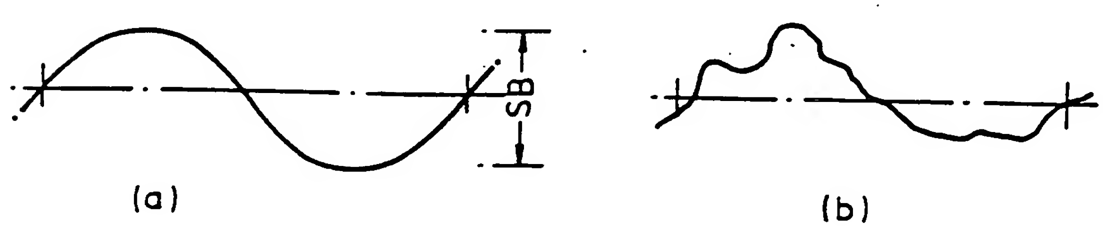

SB
(a)
(b)

Fig.10.